

THE WORLD OF CHEMISTRY

Program #6

THE ATOM

Producer Doug Bolin

Air Script: October 31, 1988

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Annenberg/CPB Project Logo and Music

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MONTAGE: Space and galaxy
shots, scientist at work, atom
graphic

NARRATOR (MUSIC under):
What is the ultimate nature of matter in
our universe? Throughout recorded
history, the human mind has pondered
this question. What are the smallest
chemical building blocks that make up
our world? For hundreds of years,
chemists proposed models of this
invisible particle, and used them
successfully. Yet only in the 1980s did
humans finally see what had been
predicted for so long, the atom.

SUPER: THE ATOM

THE WORLD OF CHEMISTRY OPEN: Montage, Music, Logo

RH in museum

ROALD HOFFMANN (SYNC):
I'm in the New York Hall of Science, a lively hands-on science museum in Queens. This quartz crystal, crystals like this have been the object of admiration by people over thousands of years, and of use. Sand, small quartz crystals as in glass and cement, and quartz crystals themselves have been used in radio receivers. But you know, when I, as a scientist, looked at this quartz crystal, what I want to see is the source of all of this perfection. I want to look into its innards. Why do these planes meet at this specific angle? What makes it so transparent? I want to take this crystal apart. I want to take it into smaller and smaller pieces, to apply to it microscopes of increasing magnification. And I can do that. And when I go to a magnification of the order of a hundred million, I will see the indivisible component of this quartz: silicon and oxygen atoms. Actually, it wasn't as easy as I've made it out to be. It took us a good 2,000 years to get to see those atoms.

Shots of machinery

NARRATOR (MUSIC under):
Using devices that range from the massive and complex to the small and simple, we have unlocked the atom and studied its structure

Atomic bomb explosion

NARRATOR (MUSIC under and atomic bomb blast SFX):

And we have learned of the incredible power held within it.

Shots of microscope, scanning machine for human brain, computer analysis of human body

NARRATOR (MUSIC under):

Each day this knowledge of the atom is applied in many ways. In medicine, signals from the atom are analyzed to produce vivid images of the body that can eliminate exploratory surgery. We can even examine mental activity in the brain.

MONTAGE: Shots of nuclear power plant, auto plant, labs, metals, telephone wires, paints, farm worker, cosmetics, fabrics, plastics on conveyor belt

NARRATOR (MUSIC and NAT SOUND under):

Nuclear reactors generate electricity for our homes and industry. In chemistry, the atom is central. Through our knowledge, we can predict and control chemical reactions. We can develop new alloys of metals, altering their properties to make them harder or more malleable, increasing their electrical conductivity or manipulating their strength. (cont.)

NARRATOR cont:

And a new generation of ceramics, superconducting and extremely strong, has been born. Our understanding of the atom enables us to create new drugs and paints, fertilizers and insecticides, cosmetics and fabrics. With our modern knowledge of the atom, we have developed new materials, materials that have found their way into every aspect of our lives. Scientists use models of the atom constantly as they investigate the chemistry of the world around us. But where did the idea of the atom come from?

MONTAGE: Ancient Greek buildings, close ups of rain on branches

NARRATOR (NAT SOUND under):

It began with a Greek philosopher, Democritus. He proposed that all matter was made up of extremely tiny particles called atoms.

Close up of chemical reaction in beaker

NARRATOR (NAT SOUND under):

Much later, in the 1800s, scientists revised the idea of the atom to explain events like this. By then, chemists were establishing that specific chemical reactions involve the combination of definite amounts of starting materials.
(cont.)

NARRATOR cont:

They also noted that, after the reaction was finished, the starting materials had yielded definite amounts of end products.

Archival photograph of John Dalton, close up of chemical reaction in beaker

NARRATOR (NAT SOUND under):
Chemists like John Dalton used the idea of atoms to explain this, proposing that during reactions, atoms combined in predictable ways. Dalton's ideas were the beginning of our modern model of the atom in chemistry.

GRAPHIC: The nucleus and the electron cloud

NARRATOR (MUSIC under):
In this model, the atom has three basic components and two basic regions. One of the components is called a proton and another, the neutron. Together, the protons and neutrons make up the first region of the atomic world, the nucleus. The number of protons is what determines the identity of the atom. Protons and neutrons are held together by incredibly strong forces in the nucleus, which is actually extremely small compared to the total size of the atom. For example, this is the nucleus of a relatively simple atom, helium.
(cont.)

NARRATOR cont:

The other region of the atomic world is occupied by the third component, electrons. This fuzzy cloud represents the space around the nucleus occupied by the electrons, called the electron cloud. The number of electrons in the cloud is equal to the number of protons in the nucleus. The electron cloud is 10,000 times larger than the nucleus. These glistening dots represent some of the possible positions of helium's two electrons as they move about the nucleus. Exactly how do the electrons move? Where are they at any given moment? No one knows the details of the electrons' motion. What is known are the chances of finding it at any given point around the nucleus at a particular moment. Where the chances are high, the cloud is dark; where they are low, the cloud looks lighter. Using indirect methods, scientists have established that atoms are all basically like this modern model.

Shots of atom imaging
instruments

NARRATOR (NAT SOUND under):

Throughout this century, scientists have imaged the atom with different x-ray techniques. Then in 1981 Gerd Binnig and Heinrich Rohrer of IBM in Switzerland invented a new microscope, producing brilliant images of single atoms.

INTERVIEW: Dr. Robert
Hamers, Research Scientist
at IBM

ROBERT HAMERS (SYNC):

Well the first time I saw atoms, it was about two or three o'clock in the morning. Of course, I was doing most of my work at night because the instrument itself is extremely sensitive to vibration, so most of our experiments are done at night or on weekends. And it was about two or three o'clock in the morning, and I was staring at this image, and I started to notice this regular pattern appearing, which I knew had to be the positions of the atoms, and it just got better and better, and I was just elated. Eventually, tears came to my eyes because I was so happy, having worked on this day and night for so long.

Dr. Hamers working with STM,
close-up of STM

NARRATOR (MUSIC under):

Dr. Robert Hamers is at IBM's research division in Yorktown Heights. He has made significant contributions to the imaging capabilities of the Scanning Tunneling Microscope, STM for short.

INTERVIEW: Dr. Robert
Hamers (cont.)

SUPER: Robert Hamers

ROBERT HAMERS (SYNC):

If you've been told ever since grade school science days that atoms are the ultimate building block of materials, now we can go in, we can actually look at those atoms, and so that's incredibly exciting to be able to do that.

MONTAGE: Images of
the atom

NARRATOR (MUSIC under):

The STM can produce both two and three dimensional images with color enhancement. Here each small cone is an atom of silicon. These spears are the atoms in gallium arsenide, a compound used in computer chips. And in this two-dimensional image, we see atoms of aluminum and silicon.

INTERVIEW: Dr. Robert
Hamers (cont.)

ROBERT HAMERS (SYNC):

Our present day understanding of the atom is that it consists of a very small nucleus consisting of protons and neutrons, and this nucleus is surrounded by a diffused cloud of electrons. So with this Scanning Tunnelling Microscope, what we're doing is mapping up the contours of these electron clouds.

MONTAGE: Needle, images
of the atom

NARRATOR (MUSIC under):

The STM uses an extremely small needle to trace the shape of each atom's electron cloud, producing images like this. Images of the tiniest particles of the elements in the world around us. Images of an idea that began over 2,000 years ago, images of the atom.

INTERVIEW: Dr. Robert
Hamers (cont.)

ROBERT HAMERS (SYNC):

One of the unique features of the Scanning Tunnelling Microscope is that, in addition to being one of the few instruments which can actually be used to observe individual atoms, it's also relatively inexpensive and provides a wealth of information. I think it's very likely that within five or ten years, certainly every chemistry department in this country will probably have at least one Scanning Tunnelling Microscope.

MONTAGE: Images of the
atom, archival photographs,
atom graphic, close-up of
chemical reactions in dishes

NARRATOR (MUSIC and NAT
SOUND under):

The STM images were a dramatic confirmation of our modern view of the atom. (cont.)

NARRATOR cont:

But long before we could actually image individual atoms, a series of simple experiments had given us information about the components within the atoms.

One of their most important characteristics is charge. Electrical charge holds the nucleus and the electron cloud together and determines the course of chemical reactions. How does electrical charge work in the atom?

Series demonstrator, Don Showalter.

DS in lab

DON SHOWALTER (SYNC):

You notice anything different? Believe it or not, I did comb my hair this morning. What you're seeing is the result of electrical charge. This device now is producing an electrical charge that is being transmitted through my body to the hairs on my head. The electrical charge is what's making them stand on end. How is this happening?

DS in lab

DON SHOWALTER (SYNC):

What you see here are four ping-pong balls covered with foil. This is a glass rod. If you rub the rod with fur, it picks up a certain kind of charge, a positive one. Matter now can be charged in one of two ways. It can be charged positively or negatively. (cont.)

DON SHOWALTER cont:

And the type of charge is very important. Let me show you why. If I take this positively charged rod and pass it near these balls, the charge is transferred to the balls, and look what happened. They repel. The balls are both positively charged, and positively charged balls repel one another.

Close up of balls and rods demonstration

NARRATOR:

When a negative charge is applied to the balls, the same thing happens. The balls become negatively charged and repel each other.

DS in lab

DON SHOWALTER (SYNC):

Now, what would happen if I took that negatively charged ball and moved it close to this positively charged ball? Let's try it and see. As we move them close together, look at that, they attract one another. So negative charges attract positive charges; unlike charges attract; like charges repel. Now, that's an important concept to learn if we're going to understand the world of the atom.

GRAPHIC: The atom

NARRATOR (MUSIC under):

So positive and negative charges attract in the atom, holding the electron cloud to the nucleus. How did we find out which components were positive and negative?

Archival photographs of William Crookes, close up of Crookes tube

NARRATOR (MUSIC and NAT SOUND under):

An experimental device developed by William Crookes helped provide the answer. The Crookes Tube. It produces a glowing stream of electrons. By using magnetic and electric fields, scientists were able to deflect the electrons. With this procedure, they were able to show that the electrons were negatively charged.

GRAPHIC: The proton and neutron

NARRATOR (MUSIC under):

In a similar experiment, another particle was discovered. It had a positive charge and was christened the proton. Much later, in a different experiment, a particle with no charge was found and named the neutron.

Close up of Crookes Tube

NARRATOR (MUSIC and NAT
SOUND under):

In every atom, equal numbers of positively charged protons and negatively charged electrons balance each other. So the overall charge of an atom is zero. The atom is neutral. But the question of how positive and negative particles were arranged in the atoms still needed resolution.

Archival photograph of
Ernest Rutherford

NARRATOR:

The first clue came from an experiment performed by a physicist, Ernest Rutherford.

DS in lab

DON SHOWALTER (SYNC):

What you see here is a recreation of the Rutherford experiment. He used an element named polonium, which gives off positively charged particles. Now, he put the polonium into a lead box, something like this. It has a small opening in it. This is a lead barrier. It has a tiny hole in it that will allow only a thin beam of positively charged particles to pass through. There's an opening here, and then here is a very thin piece of gold foil. (cont.)

DON SHOWALTER cont:

Surrounding the gold foil is this ring, which is specially coated with a material such that when a positively charged particle hits it, it gives off a flash of light. Alright. Now, what do you think would happen if those positively charged particles hit the gold foil? Well, Rutherford thought they would pass right on through the foil and hit the ring about right here. Boy, was he in for a surprise! Now, here's what actually happened.

GRAPHIC: Rutherford's
gold foil demonstration

NARRATOR (MUSIC under):

Most of the particles passed right through the foil and hit the screen behind it, but not all of them. A few were deflected sideways, and about one in every 20,000 of them bounced off the foil back towards the source.

Rutherford was astonished.

Archival photograph of
Ernest Rutherford

ERNEST RUTHERFORD (VO):

It was about as credible as if you'd fired a 15-inch shell at a piece of tissue paper and it came back and hit you.

GRAPHIC: Rutherford's
gold foil demonstration

NARRATOR (MUSIC under):

What was deflecting some of the particles? Rutherford calculated that each atom must have a nucleus, a center with a large mass and a positive charge concentrated into a small volume. The nucleus had to be massive enough to deflect the heavy particles bombarding it. And since the bombarding particles have a positive charge, the nucleus must have a positive charge to repel them. So once in awhile a particle would closely approach the nucleus and bounce back. But the majority of the particles passed right through the negatively charged electron cloud.

RH in museum

ROALD HOFFMANN (SYNC):

Rutherford's ingenious experiment gave us a simple model of the atom, the heavy nucleus with the positive charge and most of the mass, and around it like negative electrons. Then from quantum mechanics, another 20th Century development of physics, we got a picture of how the electrons move. That was a cloud, and it's represented here in the model. The electrons don't move in orbits like planets around the sun, but they do move. (cont.)

ROALD HOFFMANN cont:

Sometimes they are near the nucleus, sometimes they are far. And we can, on the average, determine where they are. The electrons, though small, are moving throughout the whole volume of the atom, and when two atoms come together -- that's actually what chemistry is all about, atoms coming together to give molecules -- it is the electrons that feel each other first, not the nuclei. This is why the chemist is so interested in electrons. They make the difference, ultimately, between carbon, hydrogen, or lead.

MONTAGE: Crystals, minerals,
ores

NARRATOR (MUSIC under):

What is it about the electrons that makes all the atoms of one substance different from all the atoms of another substance? The basic substances in the world around us each have a different number of electrons in their atoms. These electrons move about the nucleus in patterns that are different for each type of atom.

GRAPHIC: S-clouds and
p-clouds

NARRATOR (MUSIC under):

For example, we have already seen one way that electrons may move around an atom, forming a cloud that looks like this. Here is a different cloud, shaped like an hour glass. (cont.)

NARRATOR cont:

The spherically shaped cloud is called an s-cloud. The hour-glass shaped cloud is called a p-cloud. What is the difference between the s- and the p-cloud?

Close-up of image of atom

NARRATOR:

Energy. Each electron cloud has a certain amount of energy associated with it. This is called its energy state. The shape of the cloud depends on its energy state.

GRAPHIC: Energy levels

NARRATOR:

If we were to diagram the energy levels of the s- and the p-cloud, they would look like this. The p-cloud would be placed higher than the s-cloud because the electrons in it have a greater amount of energy.

Close-up of atom image

NARRATOR:

And if energy is added to the atom, it is possible for the electron to change from one cloud shape to another. As it reverts to its initial state, the atom gives off energy signals.

Chemist working in lab

NARRATOR (NAT SOUND under):
Chemists can use these signals from the electrons to distinguish between the atoms of many different substances, even when these atoms are present in very small numbers. How does this work? Environmental analysis is one example.

MONTAGE: Children playing

NARRATOR (NAT SOUND under):
In our environment, there are many trace elements. Some of them like selenium are harmful if too much is ingested but are essential to human health in small amounts.

MONTAGE: Chinese life:
street scenes, researchers,
ferry boat, food, soil, home
life

NARRATOR (MUSIC and NAT
SOUND under):
For example, thousands of people in a region of China once suffered from a disease of the heart muscle. In fact, many died from it. Researchers analyzed the residents' surroundings. Using techniques that detect the energy signals from the electrons of different elements, they tested their water, their food, their air and their soil, looking for something out of the ordinary. Finally, they identified an abnormality in the soil. (cont.)

NARRATOR cont:

It was lacking in selenium, a vital trace element. Crops grown in the soil were deficient in selenium, so there wasn't enough in the residents' diet. This led to the heart disease. But once the inhabitants started taking selenium supplements, the disease was greatly reduced.

Shots of chemists working
in labs

NARRATOR (NAT SOUND under):

Environmental analysts also use signals from the atom to detect elements that are harmful even in very tiny amounts. Lead, for example.

MONTAGE: Urban street scenes,
lead paint chips (removal and
detection)

NARRATOR (MUSIC and NAT
SOUND under):

Lead can enter our environment in many ways. Because it was used as a gasoline additive, lead was present in our atmosphere above normal levels. Much of this lead settled in the soil of urban areas, where some of it still remains. From the soil, small amounts of lead may work their way into our water supply, or our food. Our water may also pick it up from older pipes that were joined together with solder containing high amounts of lead. (cont.)

NARRATOR cont:

A most common source of lead poisoning is lead-based paint. Until a few years ago, most paint contained lead. If paint chips are accidentally ingested, their lead accumulates in the body. How do chemists use energy signals from the electrons to identify the atoms of substances like selenium and lead?

Chemist working in lab

NARRATOR (NAT SOUND under):

One technique is emission spectroscopy. Dr. Robert Watters is head of atomic spectroscopy at the National Bureau of Standards.

INTERVIEW: Dr. Robert Watters, Head of Atomic Spectroscopy, National Bureau of Standards

SUPER: Robert Watters

ROBERT WATTERS (SYNC):

Emission spectroscopy is an important part of analytical chemistry because it gives us the opportunity to find out what atoms are in a sample, and we can look at the possibility of a large number of different atoms being in the sample, and we can decide how much of each of these atoms are in a sample, pretty much all at the same time.

Shots of spectrums and
a flame burning substances

NARRATOR (NAT SOUND under):

The key to emission spectroscopy is color. When energy is added to an electron cloud, by heating it, for example, it gives off light that is a particular blend of colors. Each substance is different. Copper burns a bluish green; sodium, yellow; lithium burns red; barium is a pale green. These colors or wavelengths of light can be separated into a pattern called the spectrum. The spectrum for each particular kind of atom is different from that of every other atom.

INTERVIEW: Dr. Robert
Watters cont.

ROBERT WATTERS (SYNC):

Now the element lead has a specific set of energy levels, and the wavelength of light that is given off by electrons, excited electrons from a lead atom, would have a specific value, so that we could tell indeed we are looking at lead and not any other atom. And then the interesting thing, that is, that the number of lead atoms that are in this sample will cause a change in the intensity of this particular wavelength of light, namely, the more intense that wavelength is that we see, the greater the number of lead atoms in the particular drinking water sample that we were interested in.

Shots of a flame

NARRATOR (NAT SOUND under):
What happens to an electron when energy is added? How does it produce its unique spectrum?

GRAPHIC: Electrons in excited states

NARRATOR (MUSIC under):
Here is an electron in an s-cloud. Under normal circumstances, it maintains this energy level, neither gaining nor losing energy. This is called its ground state. When the electron in an s-cloud is exposed to energy from an external source -- for instance, when light is shown on it -- it may absorb energy and enter an excited state. If it absorbs an amount of energy exactly equal to the difference in energy between the two clouds, something unique occurs. The shape of the electron cloud changes from an s-shape to a p-shape. The electron has moved to a higher energy level. The change is instantaneous and complete. There are no stages in between the s-shape and the p-shape. But the electron tends to seek out the lowest energy level available, so once it absorbs energy and changes to the p-cloud, the electron emits the energy as a particular color of light. In the process, it goes back to the ground state, the s-cloud, a lower energy level. (cont.)

NARRATOR cont:

But as long as the energy source is present, the electron keeps flipping back and forth between the two cloud shapes. It keeps emitting the same pattern of color, the same energy signal each time it goes from an excited state back to its ground state.

INTERVIEW: Dr. Robert Watters cont.

ROBERT WATTERS (SYNC):

The energy difference is specific, in many cases, to a given atom. So that the light that is given off in the case of emission spectroscopy, the wavelength of light indicates what the energy difference was between the upper level and the lower level, and therefore, that wavelength or color of light gives us an indication as to what atom it was that we were looking at in the first place.

SUPER: THE ATOM

MONTAGE: Chemists
working in labs, program
graphics

NARRATOR (MUSIC under):

To review: Understanding the makeup of the atom is important to understanding chemistry. In our modern model, the atom has three components: positively charged protons, neutrons with no charge, and negatively charged electrons. (cont.)

NARRATOR cont:

The electrons occupy a space called the electron cloud. Different electron clouds have different shapes, depending upon their energy level. Two of the most common are the s-cloud and the p-cloud. When the s-cloud changes to a p-cloud, energy is absorbed. When the p-cloud changes to an s, energy is given off. Scientists can use a technique called emission spectroscopy to analyze these energy signals and identify what types of atoms are present.

RH in museum

ROALD HOFFMANN (SYNC):

In another exhibit at the Hall of Science, we see the many different colors emitted by atoms in lamps. In this program we've looked at the structure of the atom. We understand those marvelous electron clouds around the nucleus, and, in an image that you saw at the beginning of the program, produced by a technique called scanning tunneling microscopy, we actually showed you an atom. Chemistry, like any human enterprise, operates on many levels. With partial, incomplete understanding, it's sometimes wrong. Incredibly, it's most of the time right. (cont.)

ROALD HOFFMANN cont:

About 50 years before anyone ever knew about the atom, there was devised a remarkable chart summarizing all the properties of the atoms. That chart, called the periodic table, is the subject of our next program.

Credits, Closing Montage, Closing Music

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